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TIG Method in the Multiple Repair Welding of Long-Operated Components in the Power Industry

Abstract: The article presents the results concerning the repair welding of a long-operated waterwall using the mechanized TIG method. The tests were focused on determining the effect of a repair performed in order to remove cracks in welded joints located along flat bars opening on the tube wall side on the structure and hardness of the heat affected zone (HAZ) of a repair welded joint in the waterwall. In addition, the tests investigated the influence of multiple repair welding on the formation of structural notches in the HAZ.

Keywords: repair welding, waterwall, TIG, power engineering, HAZ

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Introduction

Rational, thorough and reliable diagnostics, inspections, repairs and revamping constitute crucial elements of supervision over power systems. These activities are particularly important in terms of objects which have significantly exceeded a scheduled service time of 100 000 hours, arising from calculations determining creep strength in time. In spite of many investments by energy producers, such as the construction of a new 1075 MW power unit in the Kozienice power plant provided with the state-of-the-art solutions, many power units in Poland have exceeded an operation time of 200 000 hours. This fact entails decisions of extending the service life of these power units based on an assessment involving the average creep strength data related to 200 000 hours of service life and positive results of diagnostic tests [1–5].

The long-lasting operation of structural elements increases the degradation of their properties due to operational damage. Structures are exposed to the locally accumulated effects of heterogeneous and non-stationary fields of temperature, mechanical stresses, environment as well as changes in heterogeneous material structure leading to changes in mechanical properties, and in cases of periodical and random excessive loads, to plastic stresses and strains.

Destructive processes present in power systems include creeping, thermo-mechanical fatigue, high-temperature corrosion, erosion as well as brittle, service and corrosion cracking. These cracks are usually formed in areas of accumulated stresses caused by mechanical and structural notches as well as by the significant gradient of temperature. Structural changes, geometry and stresses generated in welded joints

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being sources of structural changes are responsible for concentration stresses and the reduction of fatigue strength [6]. In particular, cracks are initiated in the heat affected zone (HAZ), i.e. area of diversified microstructure [7].

One of the power system elements fed with fossil fuels is the boiler furnace chamber made of a waterwall providing the leaktightness of the boiler on the flue gas side and increasing the general boiler efficiency. Commonly used flipper tubes are made of smooth tubes with flat bars or sections welded to them [8]. The waterwall operation leads, among other things, to the formation of non-passthrough cracks in welded joints along flippers, opening on the tube wall side (Fig. 1) [5, 9].

The best repair method consists in the replacement of old structural elements with new ones, yet because of technical or economic reasons, this solution is not always possible and therefore repair welding is performed. A crack in a weld is removed by replacing a tube fragment and a flat bar or by removing only the damaged fragment of a weld and making another weld [9]. In order to remove the entire welding imperfection, a cut-out part of the material should be sufficiently deep and long; craters should end with a gentle bevel from the bottom to the surface of the material being welded [10]. The repair welding of power systems is mainly performed using covered electrodes (MMA), though sometimes the TIG welding method is used.

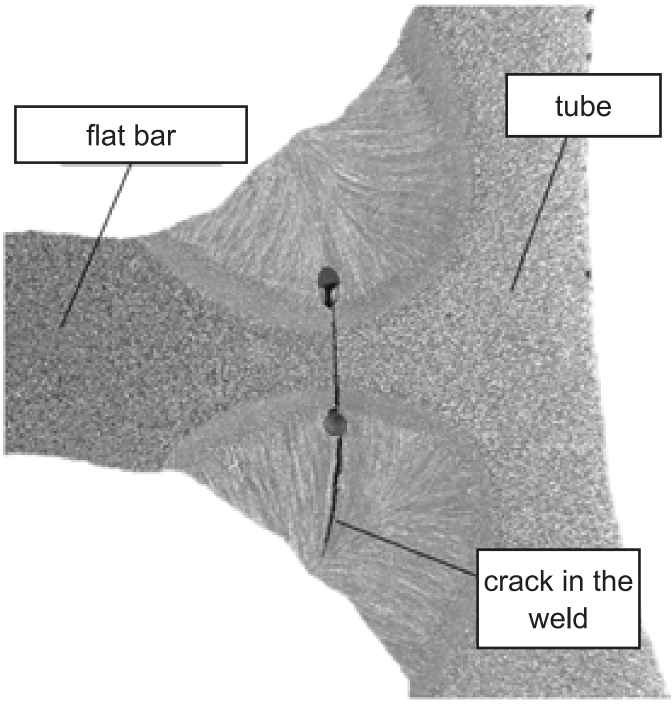


Fig. 1. Crack formed in the weld of a waterwall after long-lasting operation

Fig. 2. Welding station used for the performance of TOPTIG™ method-based repair welding

TIG Method-Based Repair Welding

The tests involved cut-out waterwall fragments made of boiler steel P265GH. The waterwall sampled for specimens had been in service for 180 000 hours. The process of repair welding was performed using the automated and robot Toptig™ method. In standard mechanised TIG welding involving the use of a filler metal, the filler metal wire is fed continuously or in a pulsed manner and supplied to the rear zone of the weld pool, directly behind arc, at an angle of between 40° and 60°. In the Toptig™ method, the mechanised filler metal wire feeding system is integrated with a gas nozzle in a manner enabling the obtainment of an angle of wire inclination in relation to the axis of the tungsten electrode amounting to a mere 20°. The Toptig™ method was developed in order to obtain a high welding rate, good quality welds free from welding imperfections and a spatter-free welding process [5, 11–13]. The welding process was performed using the Toptig 220 DC power source made by Air liquide and the Romat 310 robot manufactured by Cloos (Fig. 2).

Corrosion present on the waterwall fragments used for tests was removed by sandblasting. The weld was removed by milling. The process of milling made it possible to reduce the effect of variable factors such as the dimension and the shape of an area to be subjected to repair welding (among other things – the groove depth) and to prevent the possible overheating of the material during the removal of the weld using an angle grinder. In turn, the use of an automated welding process increased the repeatability of repair joints. The tests assumed the making of a repair weld having dimensions similar to and not smaller than those of the original weld (to be removed). The original joints were characterised by a lack of repeatability as regards the shapes and dimensions of the original welds made during the production process (Table 1). In such a case, in spite of properly selected and repeatable welding conditions, the making of a repair weld, due to the irregular effect of thermal cycles in the HAZ, could cause differences in the structure and shape of the HAZ.

The research involved 3 tests of one-time repair welding involving the removal of the primary weld. The joint microstructure observation (in the HAZ) and the measurement of hardness were performed in 6 areas (Fig. 3). The HAZ microstructure of the TIG welded repair joints was diversified in terms of phases, where the greatest differences were observed in areas 1 and 4 (near the fusion line) and 2 and 5 (Table 2). Areas 1 and 4 of the HAZ contained bainite, granular and lamellar ferrite; some joints contained greater amounts of ferrite. Areas 2 and 5 (in most of the joints) contained granular ferrite. The HAZ areas located furthest from the fusion line (areas 3 and 6) were mainly composed of granular ferrite mixed with bainite or pearlite.

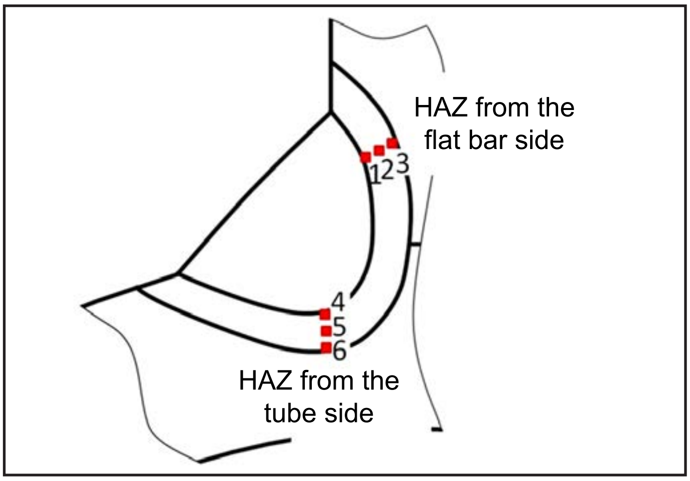


Fig. 3. Areas of microstructural observations and hardness measurements

The multiple repair welding process included additional stages aimed to remove repair welds; the two-time process involved the removal of the weld, the performance of repair welding, and the subsequent removal of the weld followed by subsequent repair welding. Analogous tests involved three, four and five-time repair welding. The microscopic metallographic tests of the joints revealed the effect of

Table 1. Macrostructure of original joints (etchant: Adler), *s* – thickness of the left and right fillet welds with deep penetration in accordance with PN-EN ISO 2553:2014-03 [14]

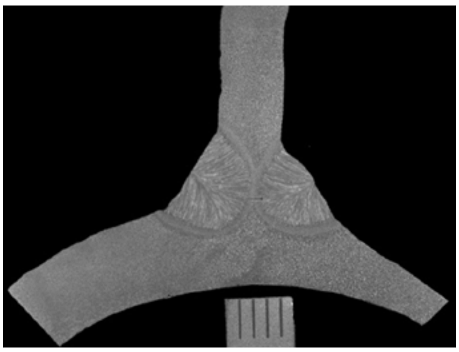
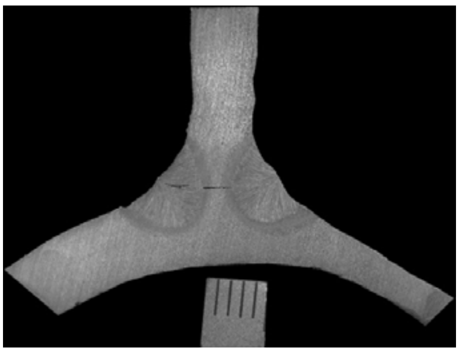
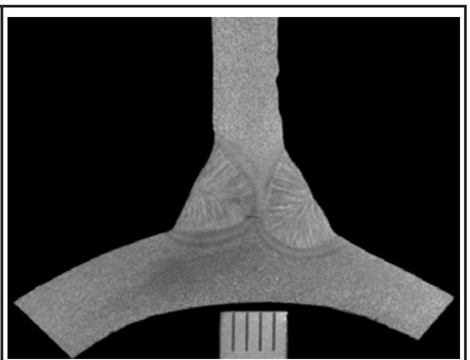
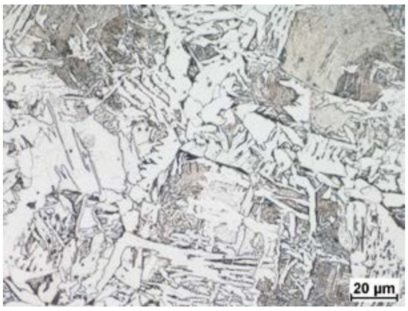
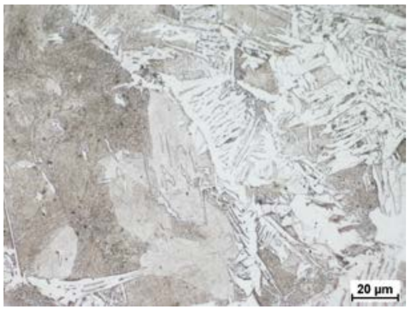
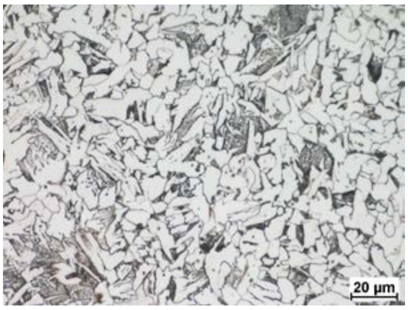
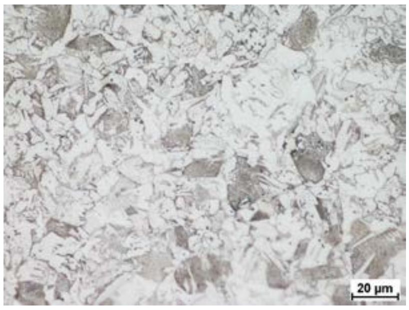
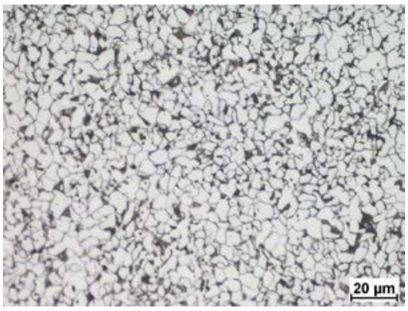
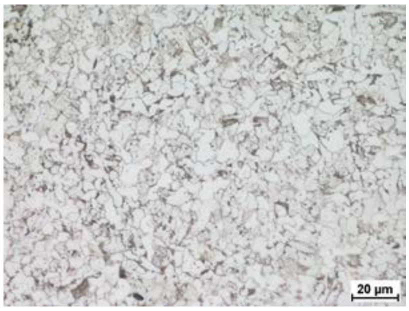
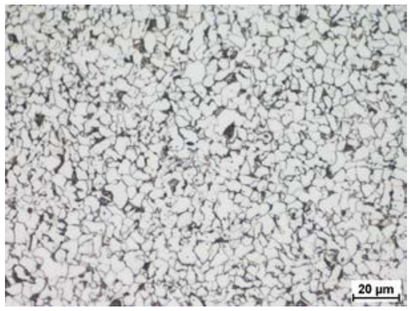
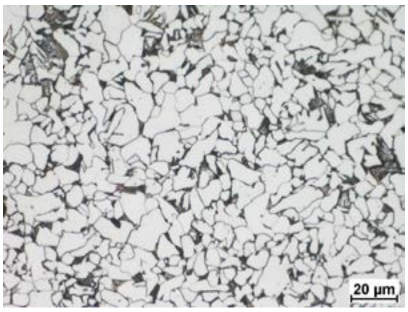
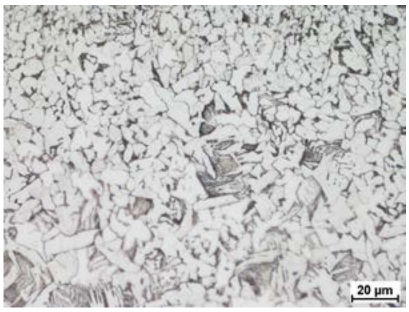
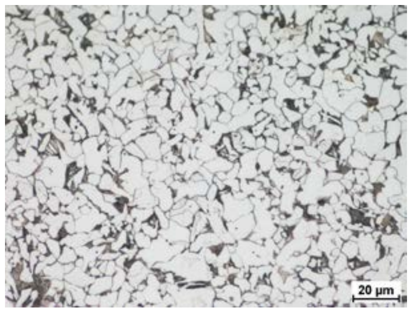
		
Sample 1, s_{left} = 4,2 mm, s_{right} = 3,5 mm	Sample 2, s_{left} = 3,8 mm, s_{right} = 3,4 mm	Sample 3, s_{left} = 4,7 mm, s_{right} = 4,0 mm

Table 2. HAZ microstructure in repair joints (two-stage etching: 3 and 2 seconds; Nital), mag. x500

	Sample 1	Sample 2	Sample 3
Area 1			
Area 2			
Area 3			
Area 4			
Area 5			
Area 6			

successive thermal cycles (arising from multiple repair welding) leading to the formation of tempered structures and to the refinement of grains in the HAZ. Similar phenomena accompany multilayer welding, where successive thermal cycles affect the microstructure (Fig. 4) [1].

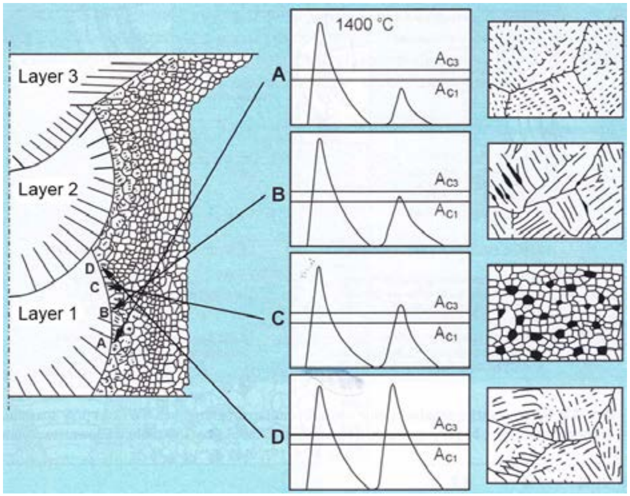


Fig. 4. Schematic representation of microstructures in the HAZ area during multilayer welding in the function of the maximum temperature of successive thermal cycles [1]

The two-process repair welding led to the partial refinement of the coarse-grained HAZ area of the first repair joint (Fig. 5), resulting from the shallower penetration depth of the second repair weld. This is indicated by the sequence of individual HAZ areas starting from the weld, i.e. coarse-grained, medium-grained, fine-grained, medium-grained and fine-grained. In addition, the HAZ area, over the same distance from the fusion line, contained zones having various structures and variously sized grains (Fig. 6), thus affecting hardness distribution and leading to the formation of the structural

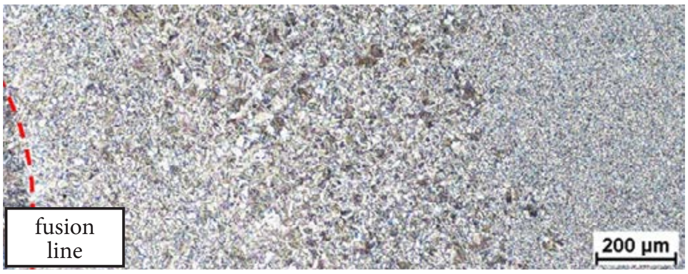


Fig. 5. Location of HAZ zones, the second repair joint; TIG welding method; weld on the left

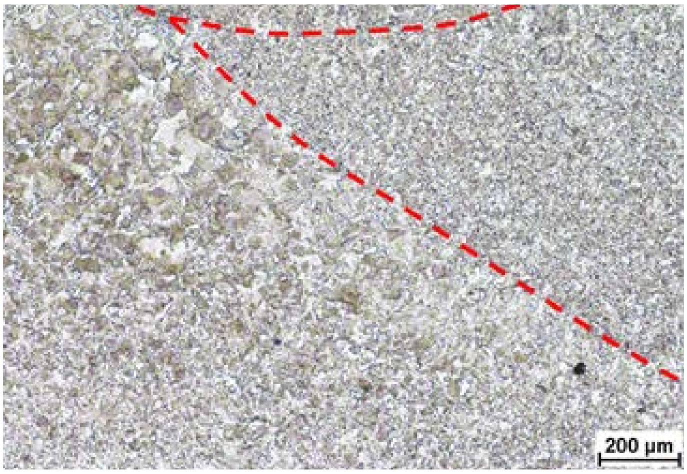


Fig. 6. Difference in the HAZ microstructure over the same distance from the fusion line (coarse-grained structure on the left, fine-grained structure on the right, weld – top), the third repair joint; TIG welding method, mag. x200

notches indicated with arrows in Figure 7. The successive repair welding processes and related thermal cycles led to the formation of various hardness areas in the HAZ. The range of hardness between individual repair joints was between 188 and 231 HV1 (area 1) and between 189 and 233 HV1 (area 4) (Fig. 8). TIG repair welding can lead to the significant gradient of hardness in the fusion line area, where the weld hardness could be by 45% higher than the HAZ hardness near the fusion line.

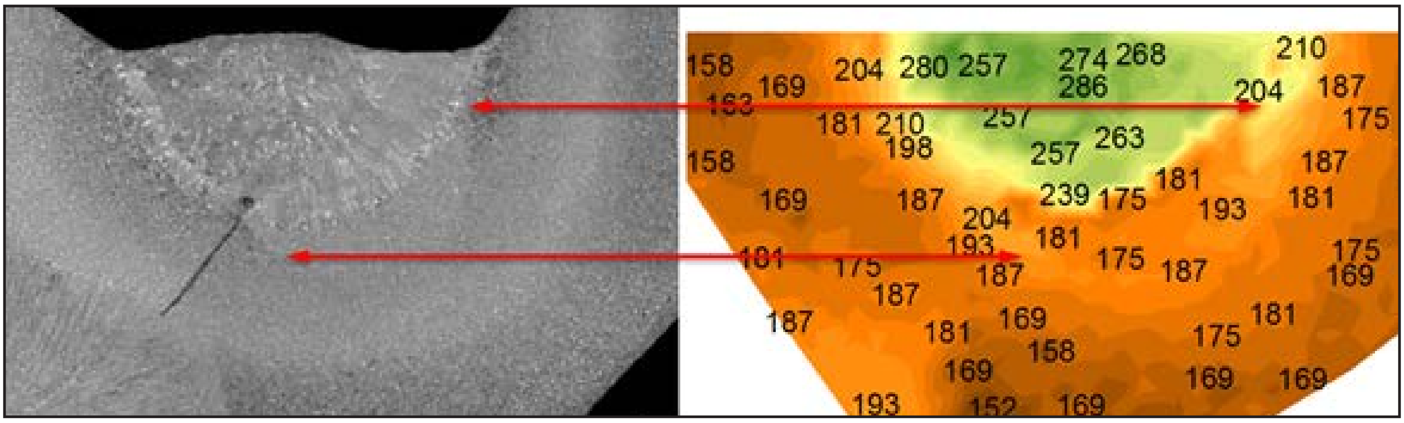


Fig. 7. Macroscopic photograph (left) and the of HV1 hardness (right) of the third repair joint made using TIG welding

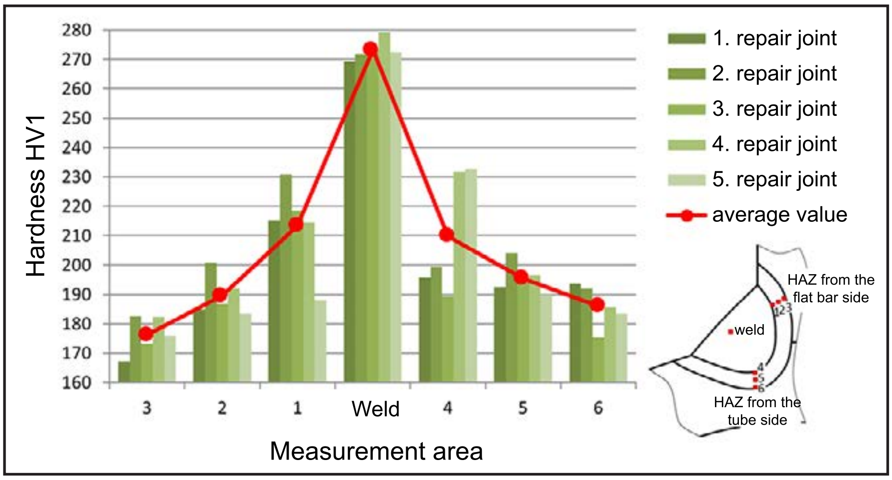


Fig. 8. Values of hardness in the weld and individual HAZ areas of successive repair welded joints

Conclusions

The above-presented tests enabled the formulation of the following conclusions:

1. The process of multiple repair welding diversifies the HAZ microstructure as regards the content of individual phases and grain sizes. Similar to multilayer welding, multiple repair welding (successive welding thermal cycles) can lead to the formation of zones having various structures and grain sizes located over the same distance from the fusion line.

2. The repair TIG welded joints are free from dangerous zones of very high hardness, yet it is necessary to take into consideration the irregularity of the field of hardness in the HAZ arising from the refinement of grains near the fusion line and structural notches, if any, in these areas. Structural notches can also result from the significant gradient of hardness in the fusion line area, where the weld hardness can be by 45% higher than the hardness of the HAZ near the fusion line. Structural notches can affect fatigue strength and gap formation as well as crack initiation and propagation necessitating repairs.

3. When preparing repair welding parameters, it is necessary to take into consideration differences, if any, in the dimensions of welds being repaired (removed) and of the groove made during the process of cutting.

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